Science and Applications of Space-Based Soil Moisture and Freeze-Thaw Observations

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MIT

International Workshop on Microwave Remote Sensing for Land Hydrology Research and Applications [October 2008]

Massachusetts Institute of Technology

Translation

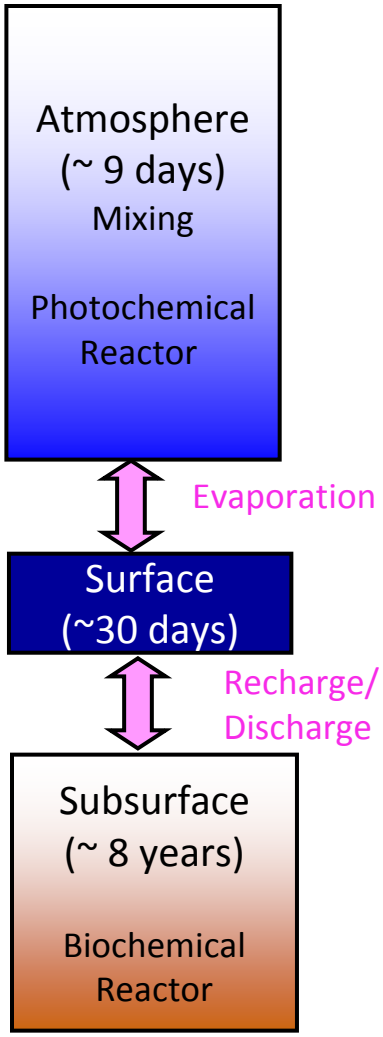
"Science and Applications of Space-Based Soil Moisture and Freeze-Thaw Observations"

or what are some of the compelling uses of the data?

Grand Challenges in Water Cycle and Its Remote Sensing

Mapping Evaporation and Recharge

1. Fluxes that are first-order determinants of biogeochemical cycles
2. Fluxes that to first-order determine and are determined by vegetation distribution
3. Fluxes that have most dramatically changed already in response to human activity.
4. Fluxes that link the slow and fast components of the water cycle
5. Fluxes that limit rate of sustainable use of surface waters and groundwater aquifers



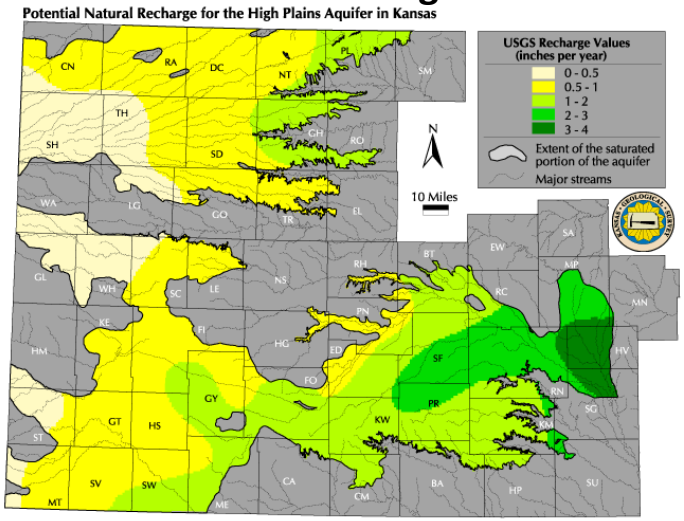
Recharge: Currently Totally Unobserved

Strong links to:

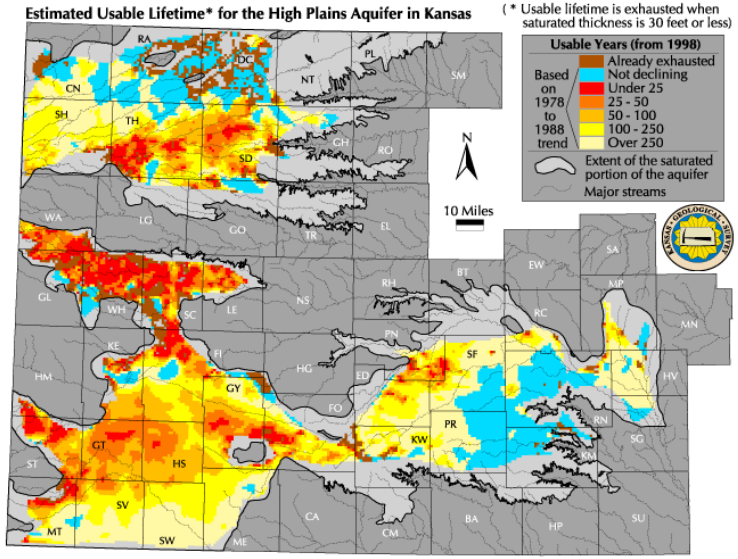
a. topography,
b. vegetation,
c. partitioning among water balance components at surface

Key to sustainable resource use.

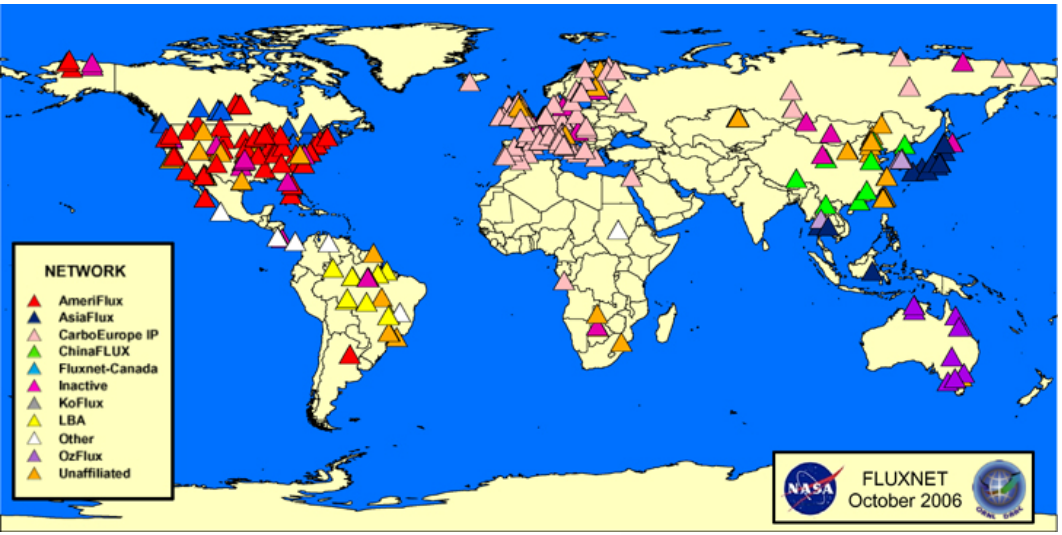
Potential Recharge



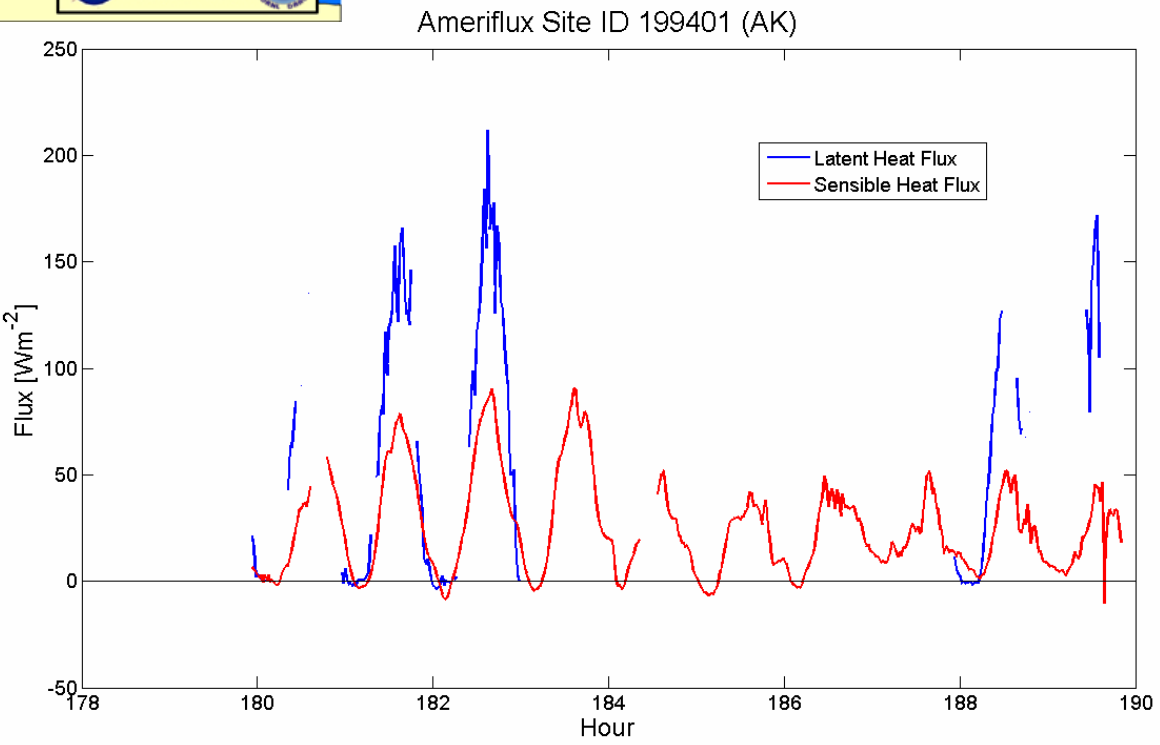
Time-to-Depletion



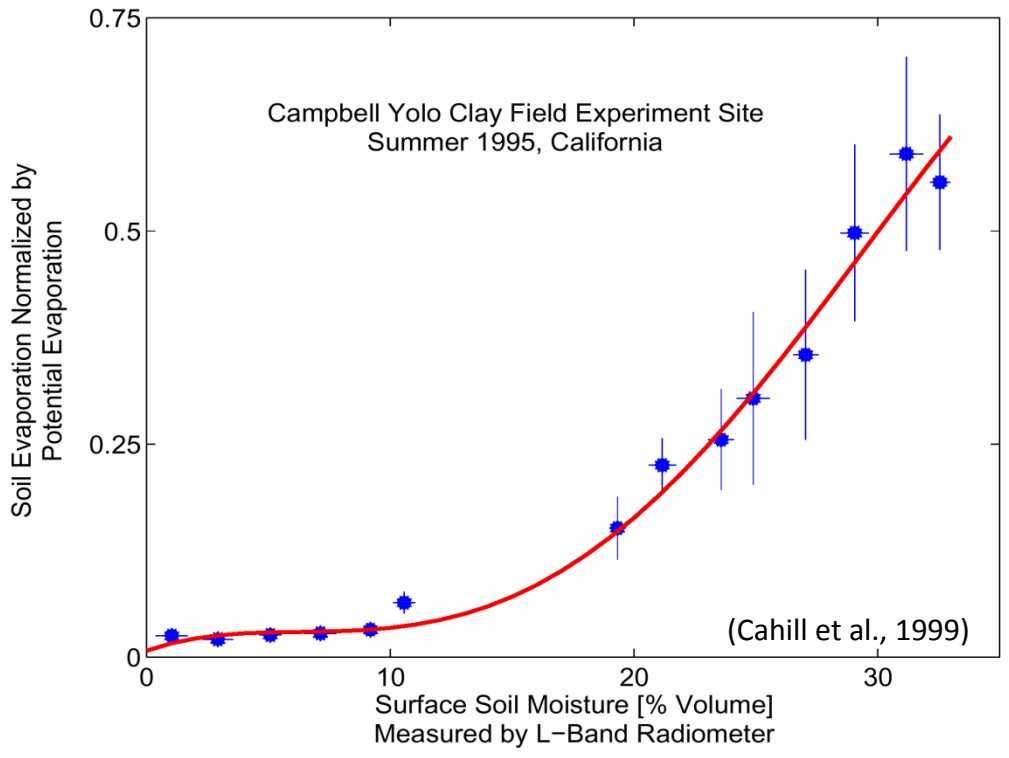
Evaporation: Even Climatology is Unknown



Flux networks



Key Determinants of Land Evaporation



Latent heat flux (evaporation) links the water, energy, and carbon cycles at the surface.

All models of water and energy balance (LSM or SVATs) include (explicitly or implicitly) a form for the closure:

e.g., $\beta(\theta)=E/E_p$ or $r_g(\theta)$ …

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Parameterized Closure Function But Without Evidence

NOAH

model grid cell and

$$\beta = \left(\frac{\Theta_1 - \Theta_w}{\Theta_{\text{ref}} - \Theta_w} \right)^f \qquad (7)$$

represents a normalized soil moisture availability term where Θ_w is the wilting point and Θ_{ref} is the field capac-

$$F_4 = \sum_{i=1}^{n} \frac{(\Theta_i - \Theta_w) d_{z_i}}{(\Theta_{\text{ref}} - \Theta_w) \left(\sum_{j=1}^{n} d_{z_j} \right)},$$

CLM

functional type and the soil water potential of each soil layer

$$\beta_t = \sum_i w_i r_i \geq 1 \times 10^{-10} \qquad (8.10)$$

where w_i is a soil dryness or plant wilting factor for layer i, and r_i is the fraction of roots in layer i.

The plant wilting factor w_i is

$$w_i = \begin{cases} \dfrac{\psi_{\max} - \psi_i}{\psi_{\max} + \psi_{sat,i}} & \text{for } T_i > T_f \\ 0 & \text{for } T_i \leq T_f \end{cases} \qquad (8.11)$$

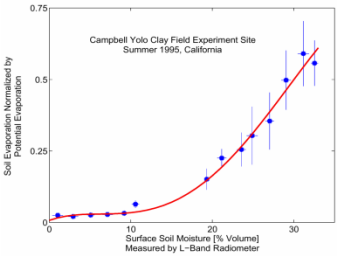
"...Let the rate of loss of water from a leaf be denoted by T, then

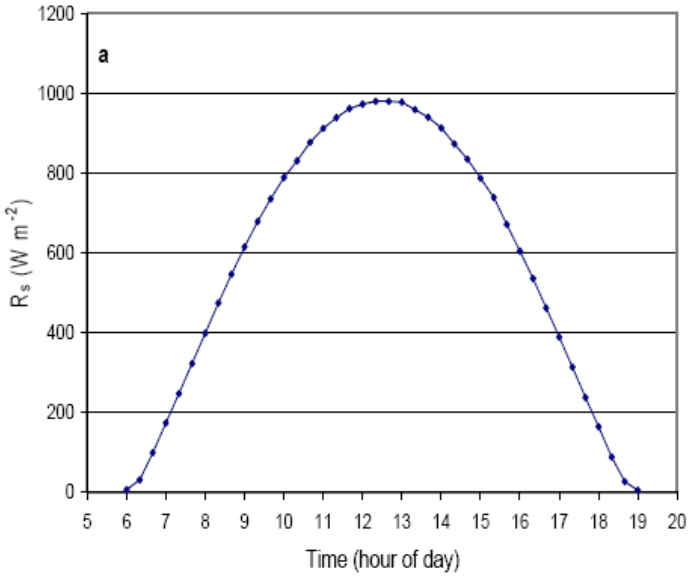
$$T = K\{F(\theta_{leaf}) - w_{air}\}$$

here K is the conductance of the stomatal openings and $F(\theta_{leaf})$ is the saturated vapour density at θ." [*Richardson*, 1922].

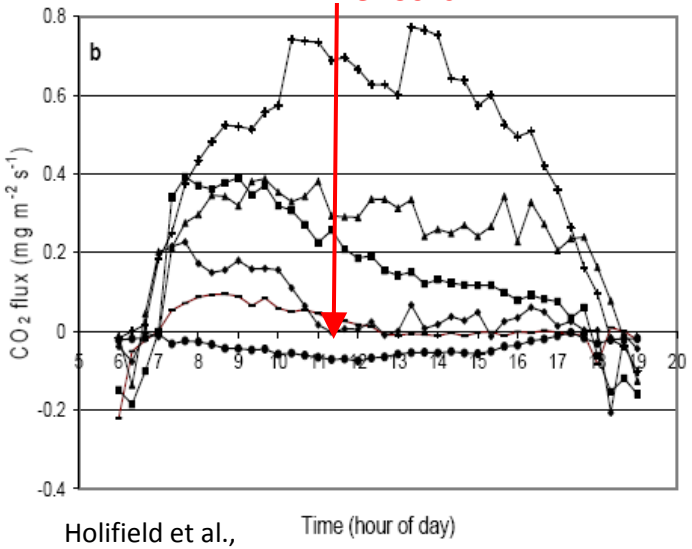
Carbon Dioxide Exchange: Response to Drying

Water and energy closure function

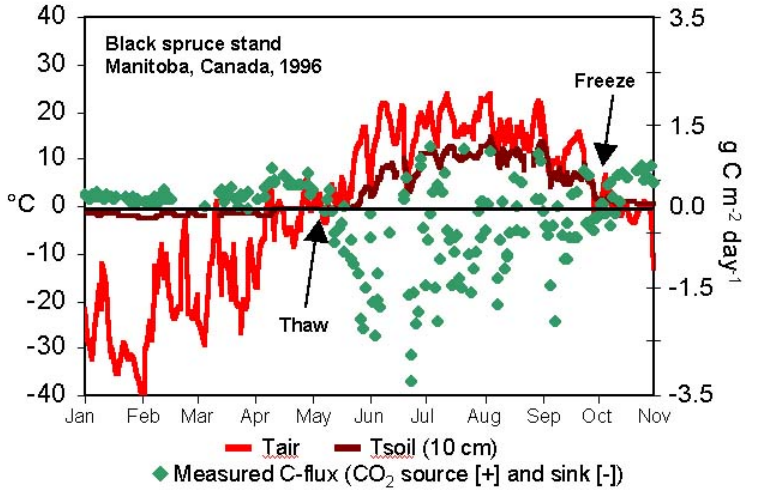


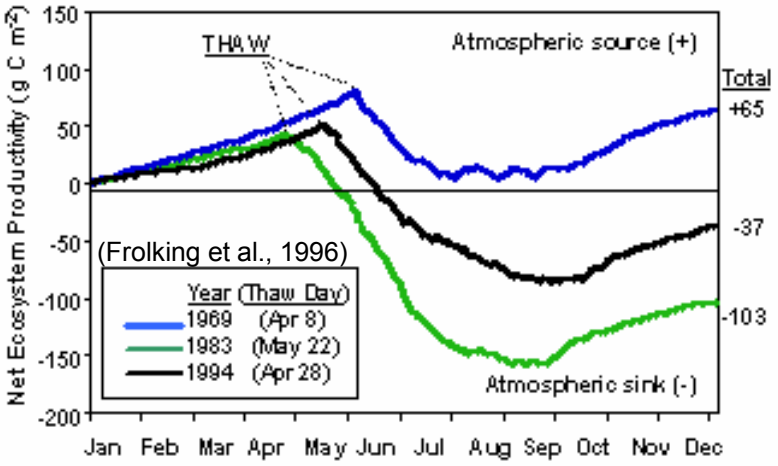


Drier Soils



Holifield et al., USDA-ARS Arizona

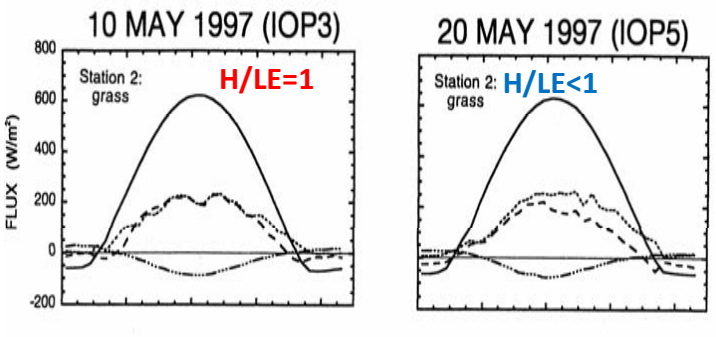


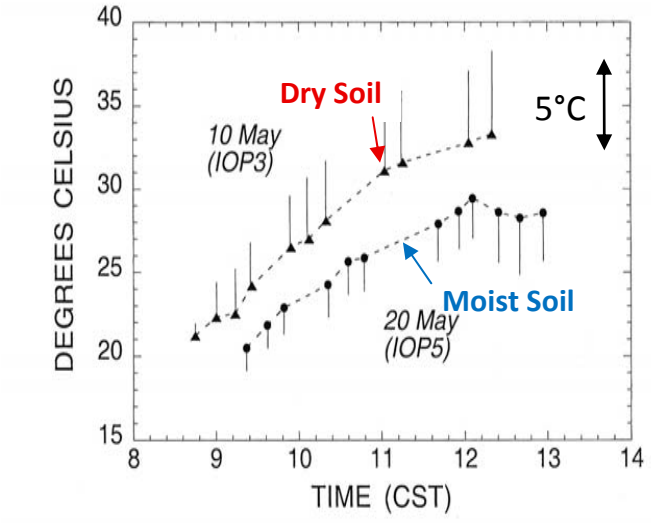


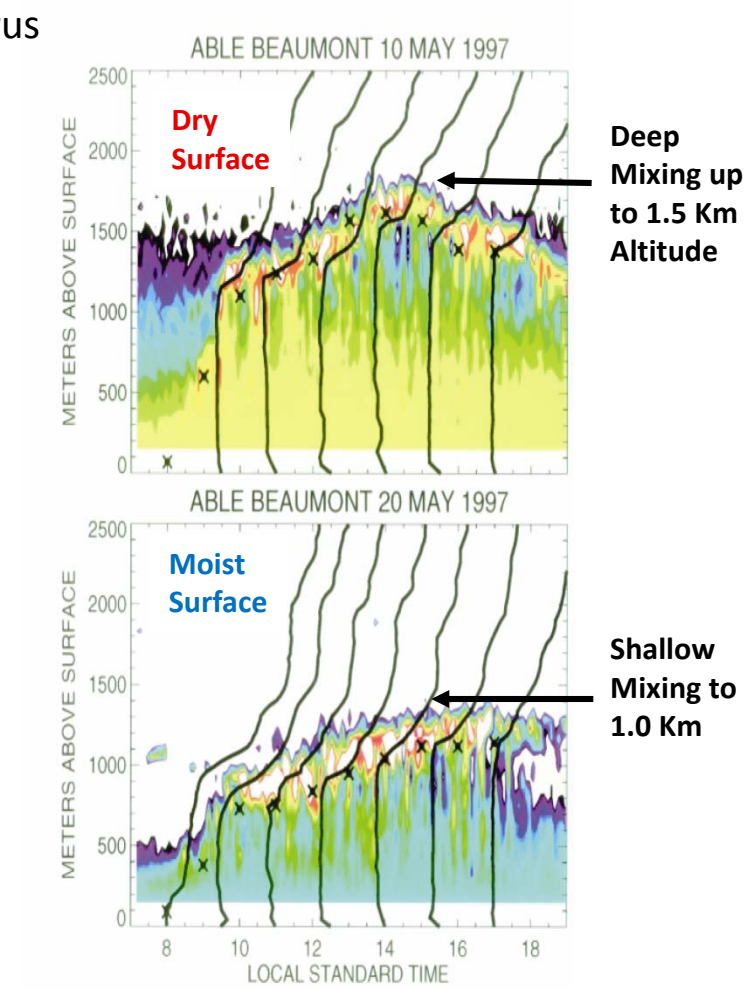
1. What is the functional form of the water-energy-carbon balance closure?

Extension Through Land-Atmosphere Interactions

May 10: Dry soil. Clear with scattered to broken cirrus
May 18: 90 mm Rain
May 20: Moist soil. Mild winds and clear.







Deep Mixing up to 1.5 Km Altitude

Shallow Mixing to 1.0 Km

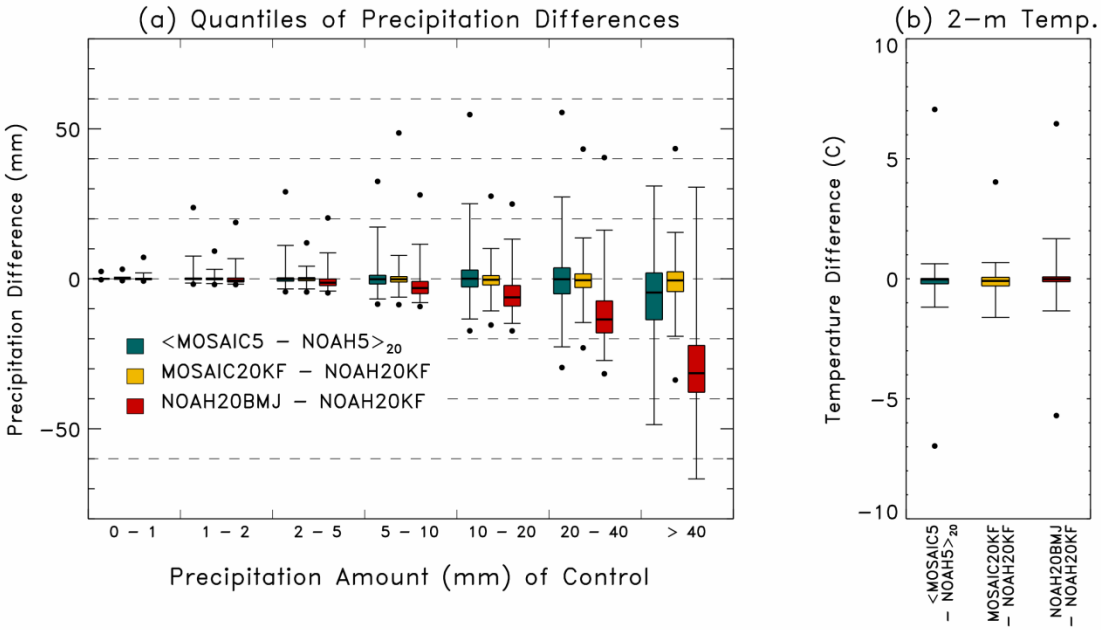
When/where in water-limited (*vs*. energy-limited) evaporation regimes soil moisture is a determinant of the evolution of the lower atmosphere.

CASES'97, *BAMS*, 81(4), 2000.

Frontiers in Enhancing NWP Skill

Sutton et al. (2007): Will Perturbing Soil Moisture Improve Warm-Season Ensemble Forecasts? A Proof of Concept, *Monthly Weather Review*, 134, 3174-3189.

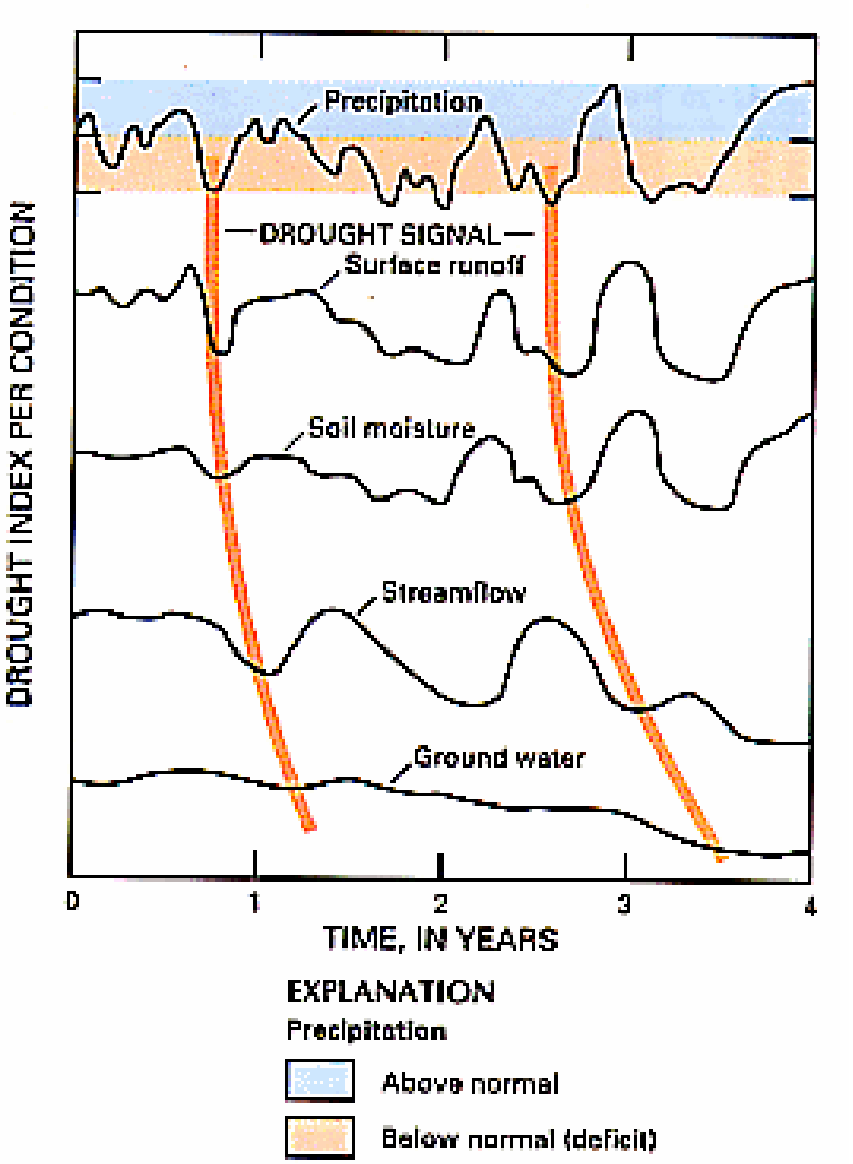
NOAA-FSL and NCAR Study



"…changes to 5-km forecasts due to soil moisture differences were almost as large as the changes to 20-km forecasts due to using an alternate convective parameterization, previously determined to be a large source of uncertainty in ensemble forecasts…"

"…The results presented here suggest that short-term temperature and precipitation forecasts can indeed be changed as a consequence of changing the soil moisture…"

Seasonal Predictability: Memory of Land System



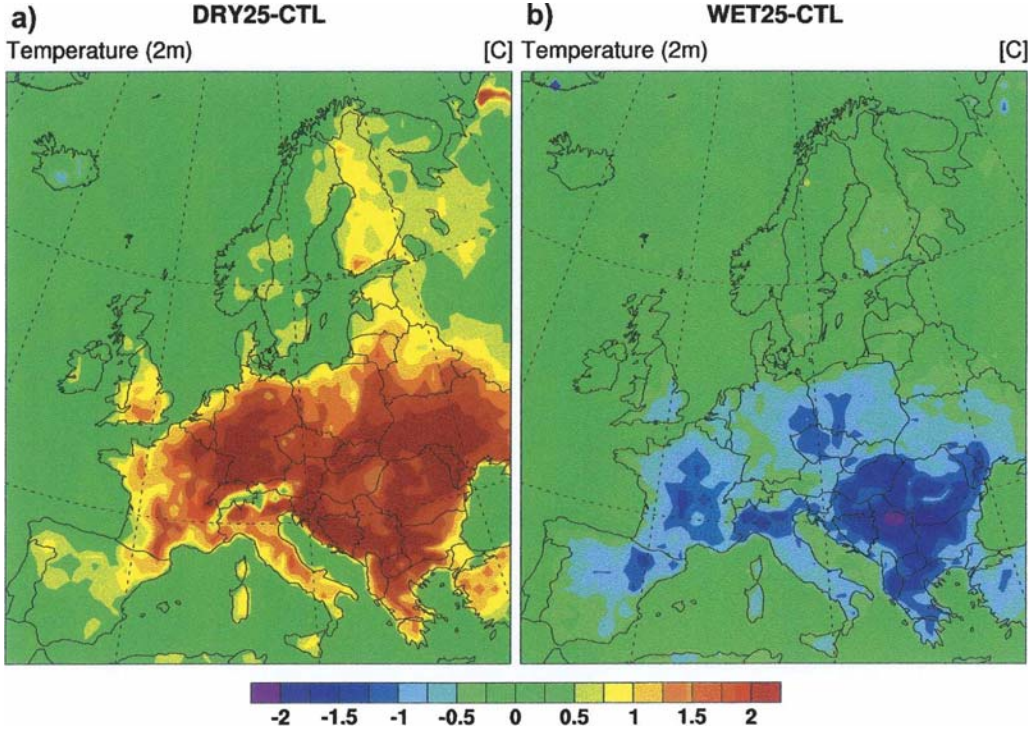
Cascade of Time Scales

McNab and Karl (1989)

Applications of Seasonal Predictability

Fischer et al. (2007): Soil Moisture–Atmosphere Interactions during the 2003 European Summer Heat Wave, *Journal of Climate*, 20, 5089-5099.

European heatwave cause 35,000 deaths, *New Scientist*, Oct. 10, 2003

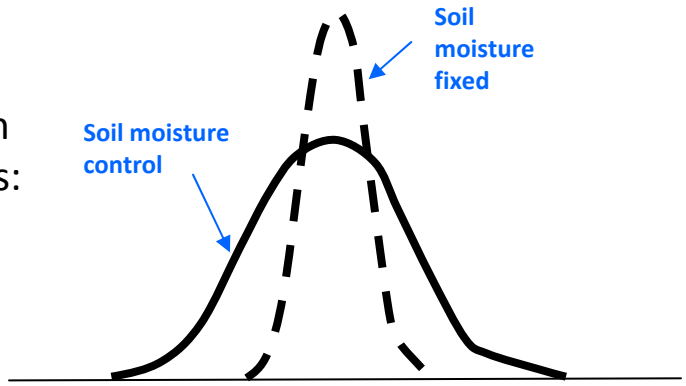


"…perturbed spring soil moisture shows that this quantity is an important parameter for the evolution of European heat waves…"

"…Simulations indicate that without soil moisture anomalies the summer heat anomalies could have been reduced by around 40% in some regions..."

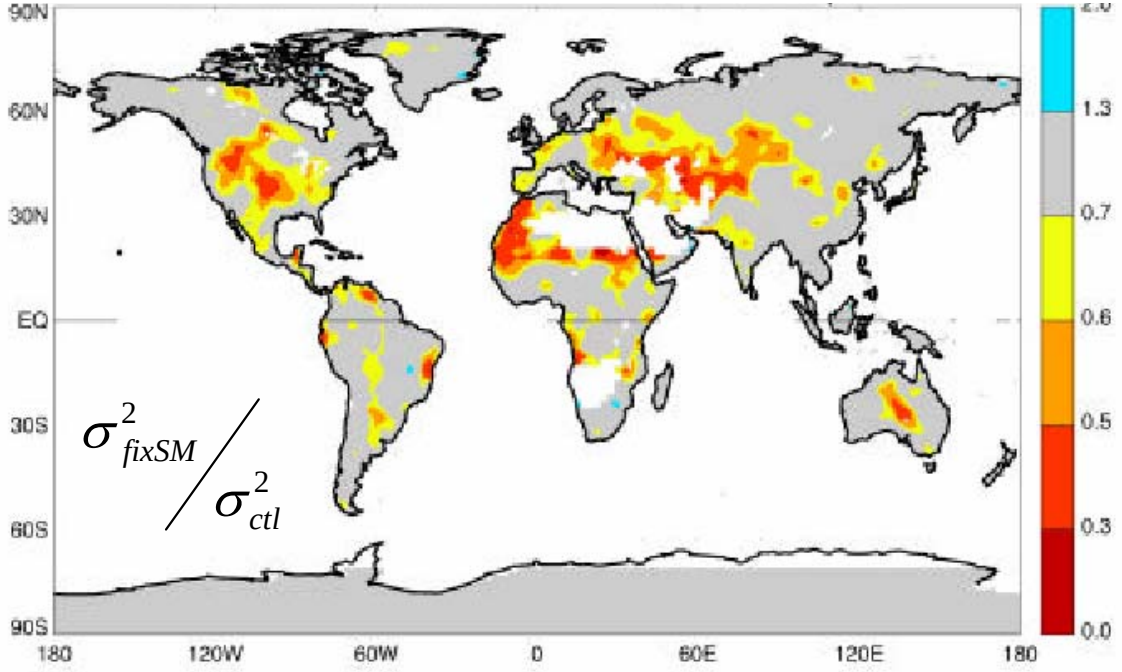
Seasonal Predictability Impacts

Ensemble Precipitation Distributions:



2. What are the dominant evaporation regimes?

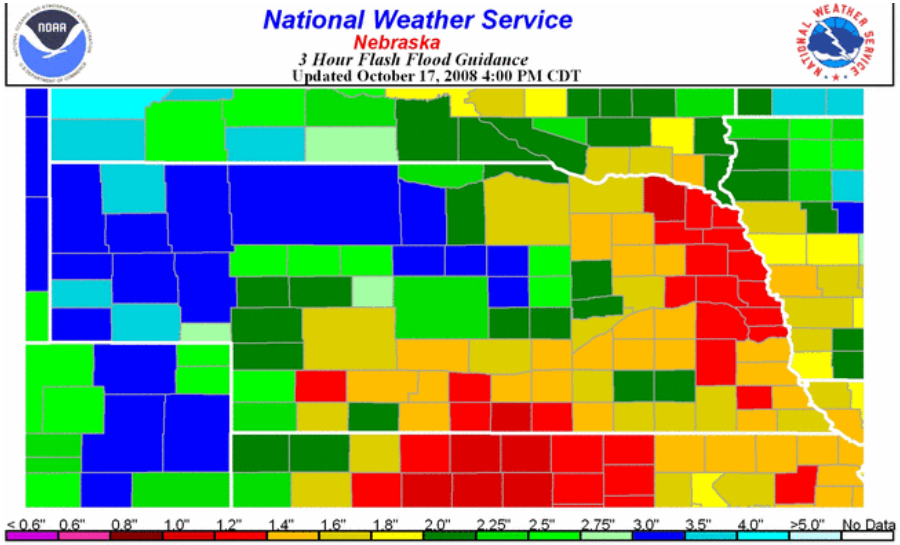
Multi-Model Consensus of Regions Where Soil Moisture Impacts Seasonal Precipitation



Koster et al. (2004), *Science*, 305, 1138-1140.

Operational Hydrology

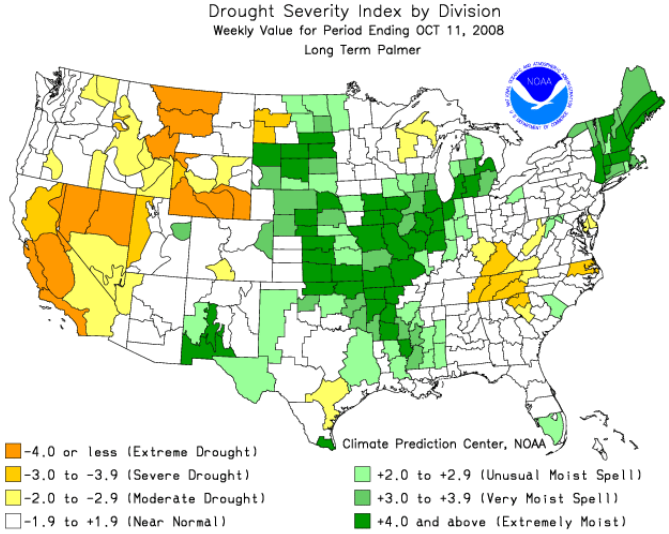
Current NWS Operational Flash Flood Guidance (FFG)



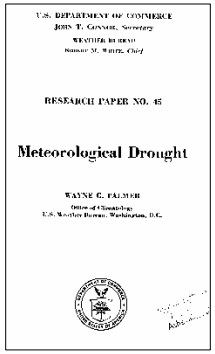
Empirical Surface Soil Moisture Deficit

$$API_t = K \cdot API_{t-1} + P_t$$

Current Operational Drought Indices by NOAA and National Drought Mitigation Center (NDMC)



Empirical Surface Soil Moisture Anomaly

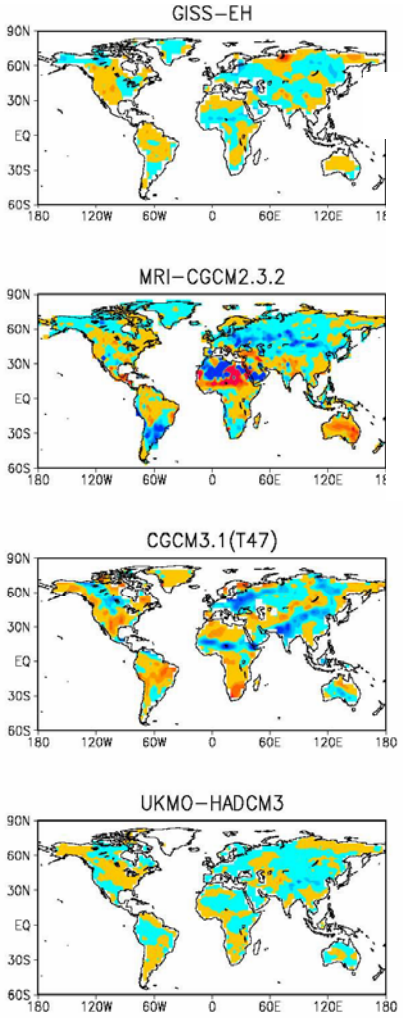


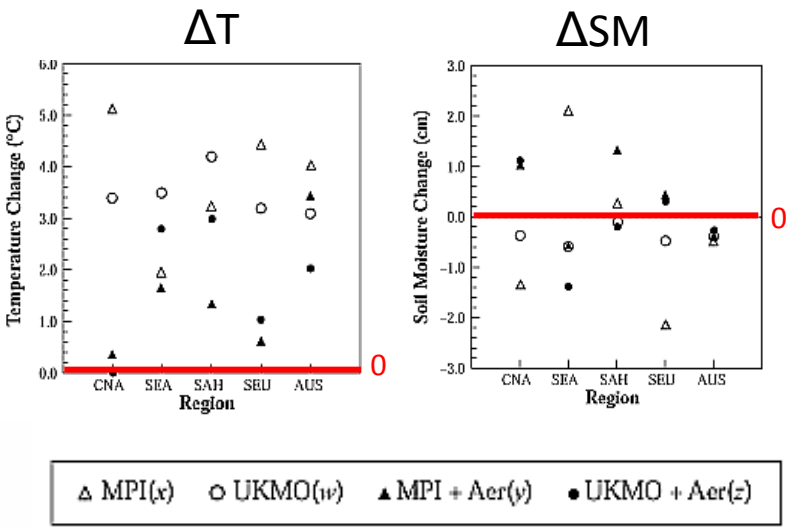
Palmer, 1965

3. How to prepare grounds for modernization of operational services?

Imperative for Climate Change Science

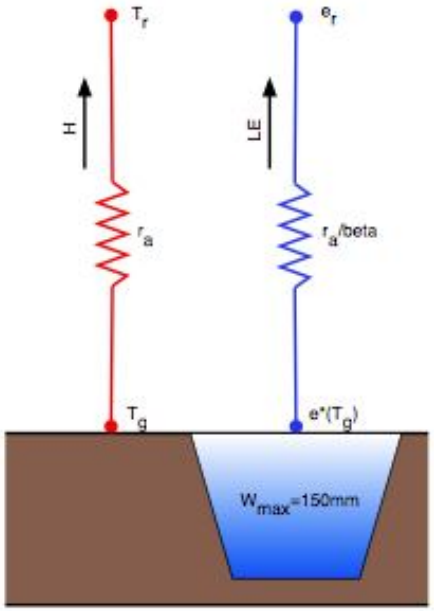
Li et al., (2007): Evaluation of IPCC AR4 soil moisture simulations for the second half of the twentieth century,
Journal of Geophysical Research, 112.

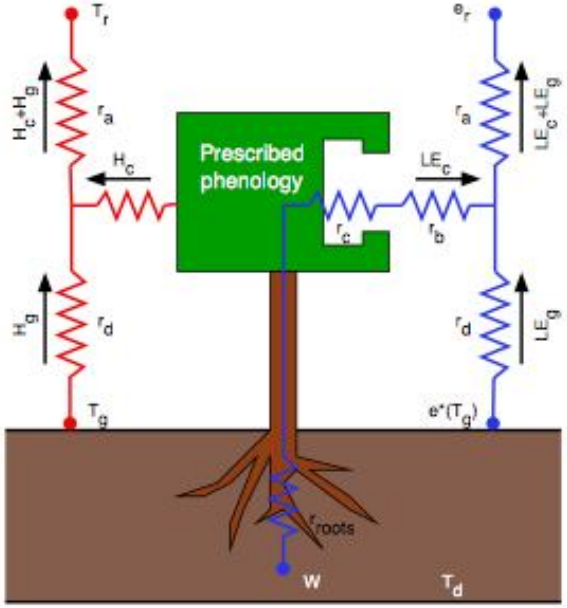


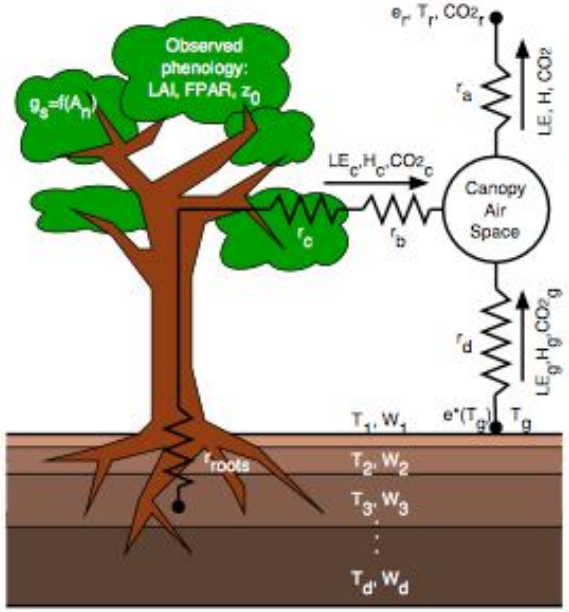


Projections of Summer Soil Moisture Change ΔSM: Disagreements in *Sign* Among IPCC AR4 Models

Evolution of Land Surface Models (LSMs)







<u>First Generation</u>:

Water Availability as a Reservoir

<u>Second Generation</u>:

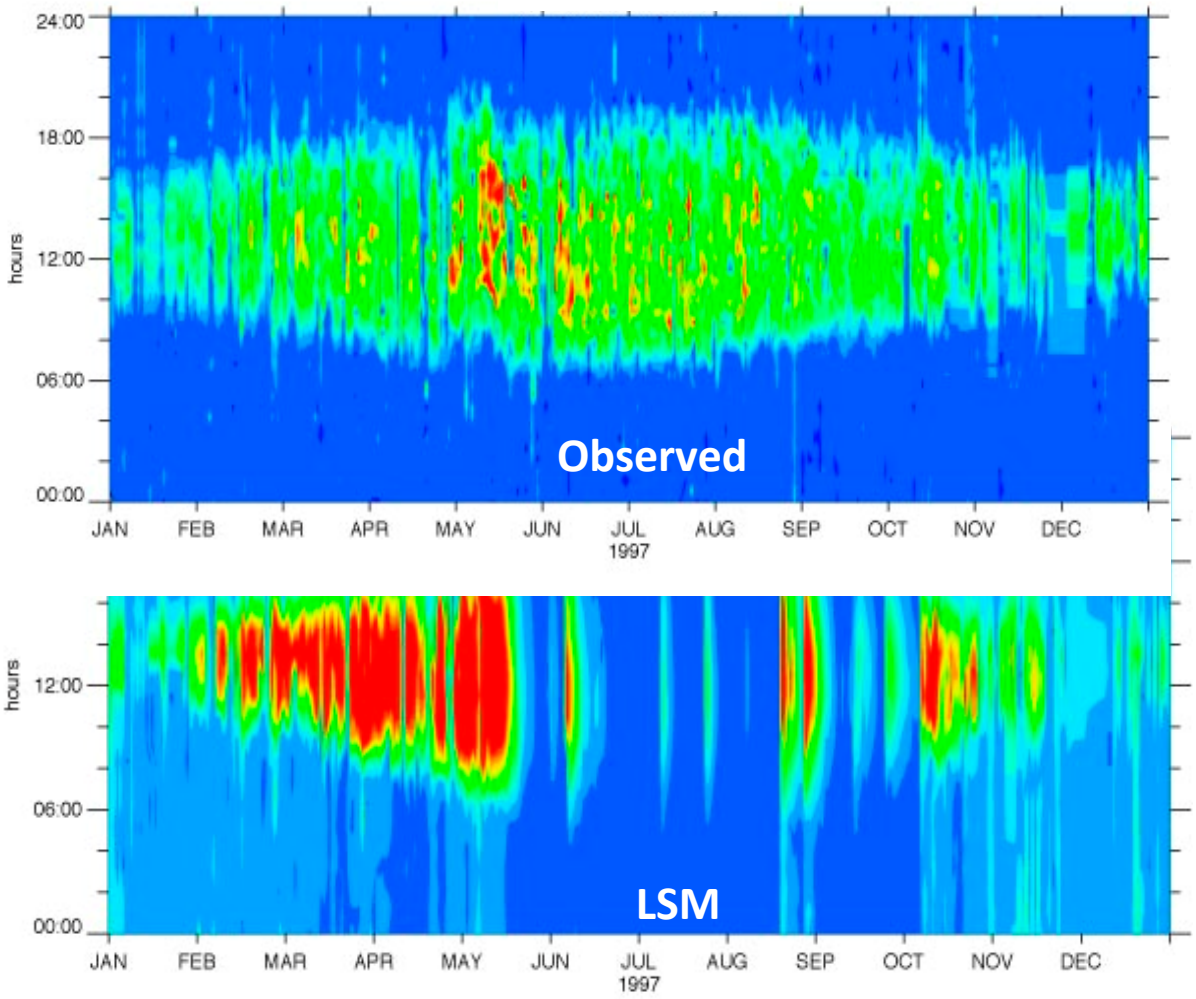
Heat and Moisture Flux Across Resistance Networks

<u>Third Generation</u>:

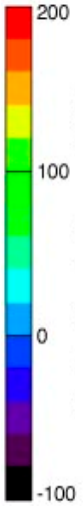
Add Carbon Exchange to Canopy Fluxes

R. Stöckli and P. L. Vidale (ETH)

How Good are LSMs in Representing Basic Dynamics?



LE [Wm^{-2}]

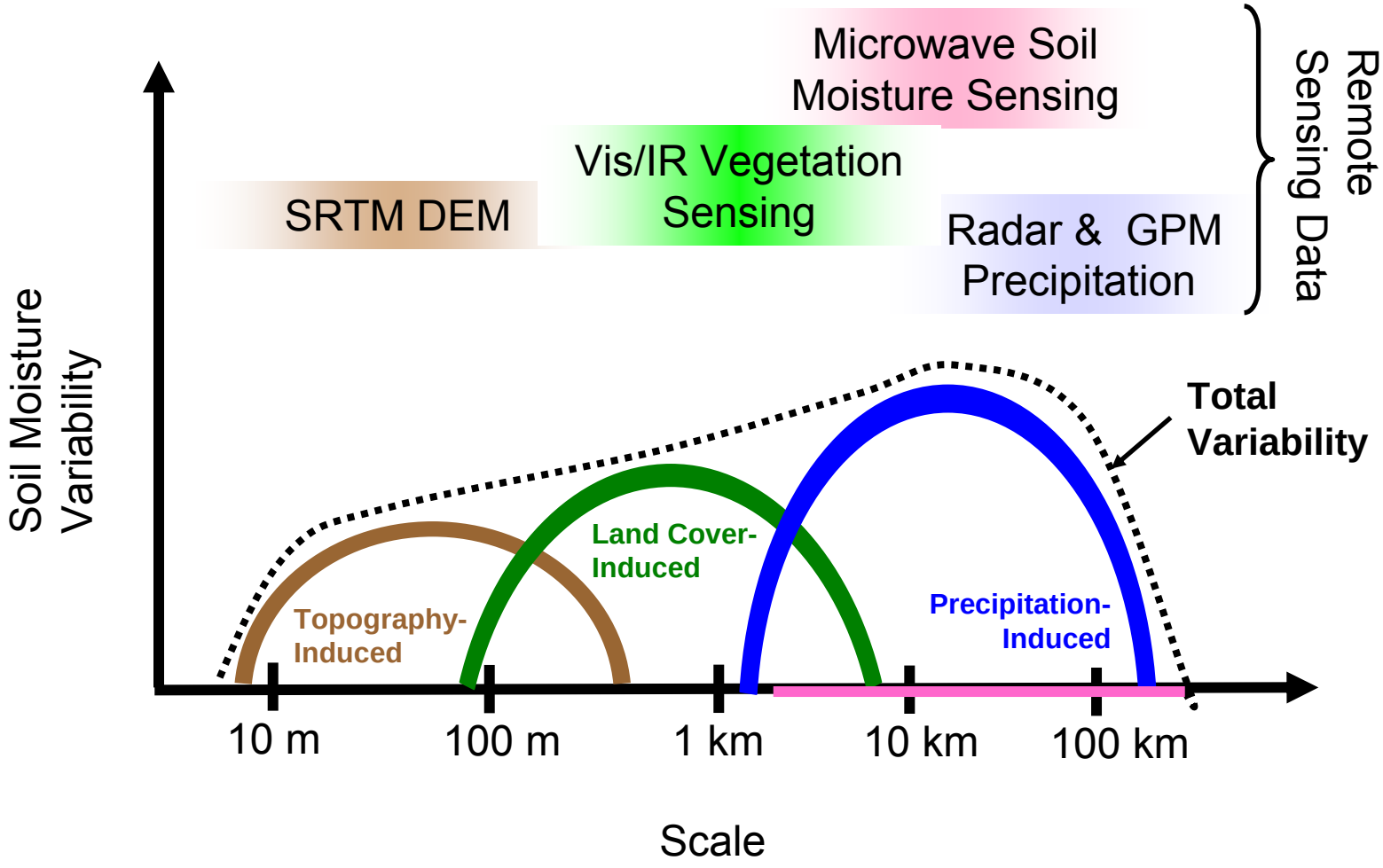


R. Stöckli et al., 2005: *Theoretical and Applied Climatology* , 80(1-2).

4. LSM (even with runoff output calibration) fail as scientific tools.
   With what protocols will observations of the state variable change that?

Constraint LSMs with Observations: Data Assimilation

1. Combine varied information sources
2. Estimate fluxes and other derived variables



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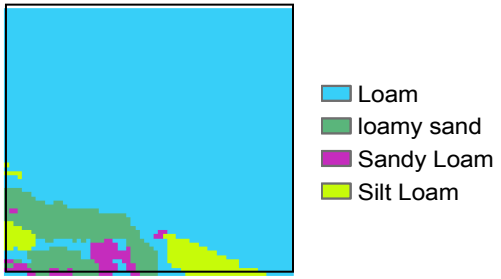
Sources of Variability

Modeled variables and observations are combined in proportion to their uncertainty.

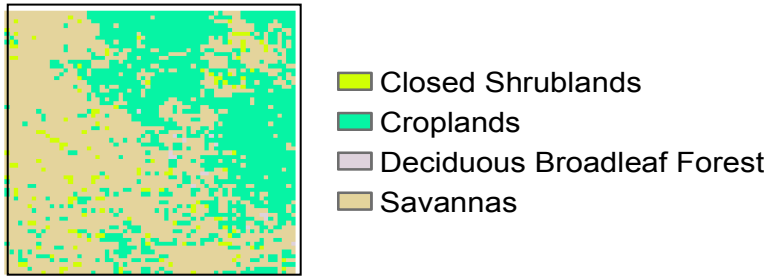
In meteorology/oceanography no model error is assigned since intrinsic chaos (growth modes) serve as model uncertainty.

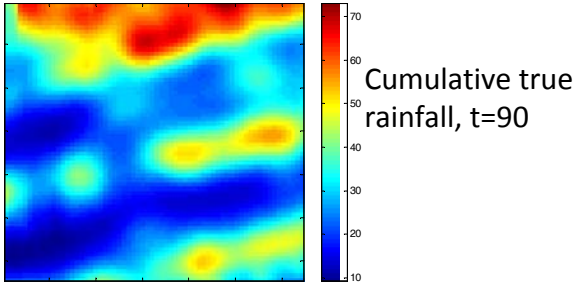
In hydrology parameters and micromet forcing are given error. Where and what amount?

Soil type



Land cover



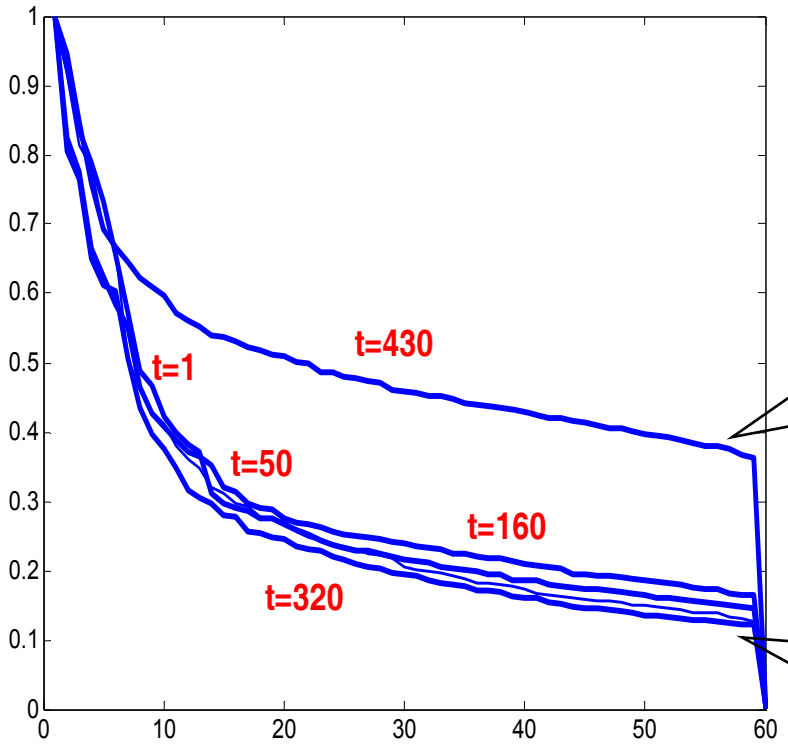


Cumulative true rainfall, t=90

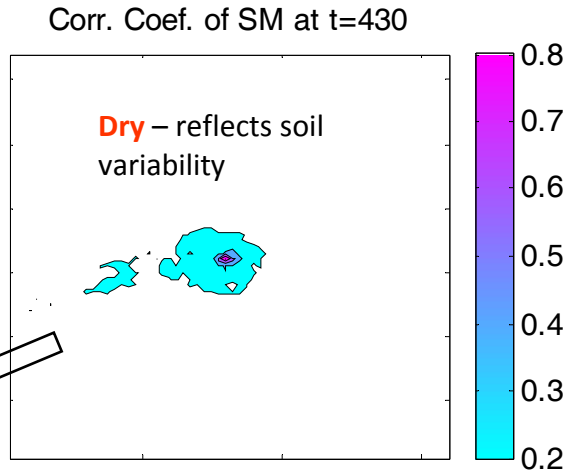
Spatially correlated precipitation and soil properties (errors)

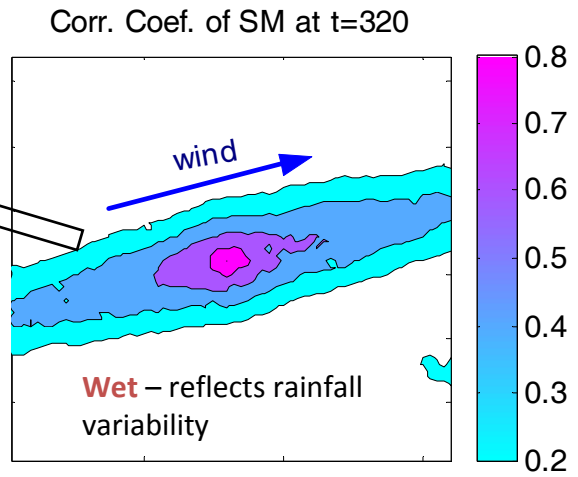
Spectrum of State Covariance Matrix

SVD of the first layer soil moisture covariance matrix is performed at some typical times



Spectrum of top layer soil moisture at different times

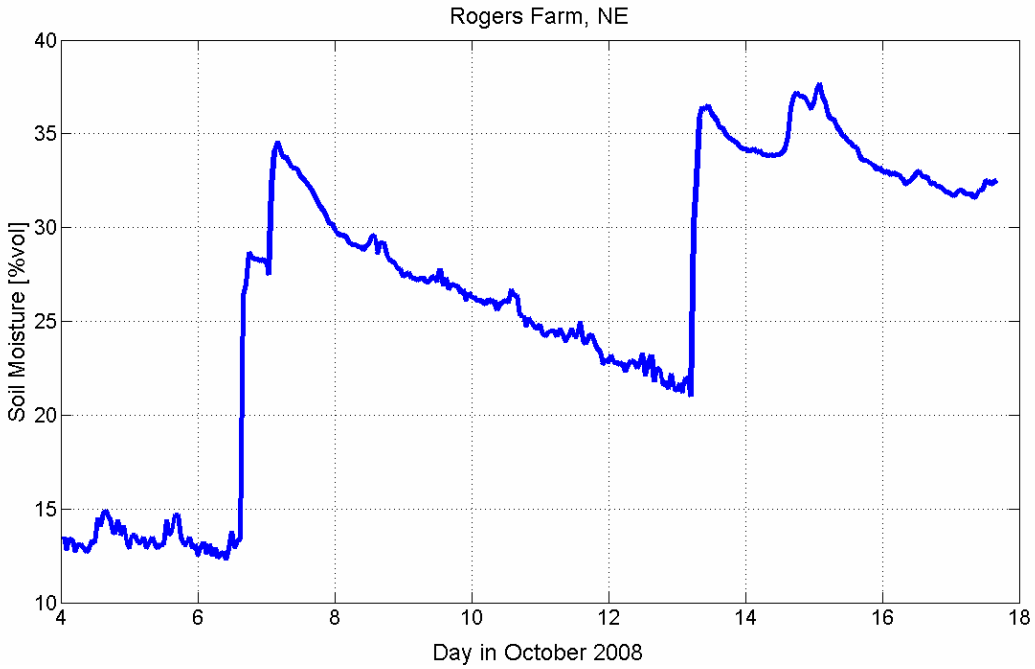




Correlation structure for the center point

Ahanin et al. (MIT, 2007)

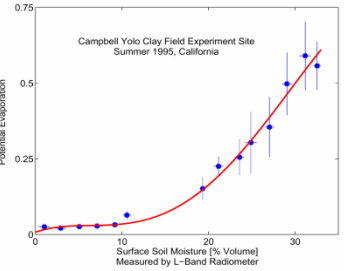
What is Different About the Land Problem in Data Assimilation?



Barrier to Information

5. How should uncertainties in models and observations be defined to bring consistency to the data assimilation industry?

Summary: How to Get There From Here Given Space-Based Obs?



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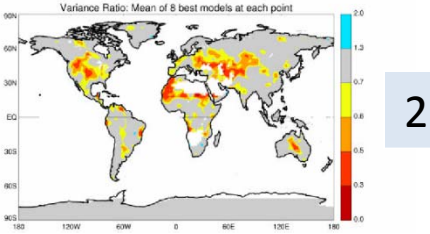

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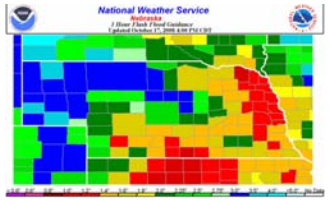
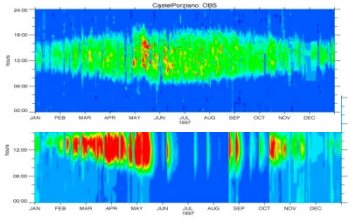
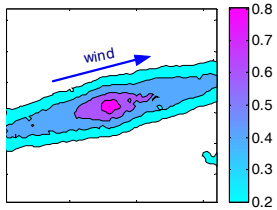


3. How to prepare grounds for modernization of operational services?





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